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Evaluation and updating of LORAC navigation system on Monterey Bay

Durkee, Andrew Franklin

Monterey, California. U.S. Naval Postgraduate School

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EVALUATION AND UPDATING OF LORAC NAVIGATION SYSTEM ON MONTEREY BAY

Andrew Franklin Durkee

United States Naval Postgraduate School

THESIS

EVALUATION AND UPDATING OF LORAC

NAVIGATION SYSTEM ON MONTEREY BAY

by

Andrew Franklin Durkee

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Evaluation and Updating of LORAC

Navigation System on Monterey Bay

by

Andrew Franklin Durkee
Lieutenant, United States Coast Guard
B.S., United States Coast Guard Academy, 1963

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ABSTRACT

A LORAC system of navigation has been established in the Monterey Bay area and is intended for use in the field of ocean sciences research. It operates on a phase comparison principle and provides highly accurate navigational fixes without complex timing circuitry. Short-term phase stability of the system was studied and methods of remote control and lane identification were investigated. Some equipment modifications were made to incorporate desirable features in the system, but further modernization may be necessary if long periods of continued use are expected. A general plotting program for the CALCOMP-563 plotter was written to produce chart overlays for existing nagivational charts and is included as Appendix B. The overlays can be tailored to fit any scale chart in the area of intended operation and the inputs to the grid generation program can be varied if the system parameters are changed.

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I. INTRODUCTION

LORAC uses the principle of phase comparison of two radio frequency signals which have the same origin, but travel to the phase measuring equipment over two different paths. The radio frequencies, generated by two continuous-wave transmitters, produce, by heterodyning, audio signals between which the actual phase measurements are made. The two transmitters operate at frequencies f_1 and f_2 respectively and the audio frequency is (f_1-f_2). A reference signal is established by receiving and detecting this audio frequency at a fixed point and using it to amplitude modulate a third transmitter. This transmitter operates at a frequency f_3 and is called the reference transmitter.

A. POSITION FINDING

Positions are determined by the use of a mobile receiver. This receiver is tuned to the average frequency of f_1 and f_2. It receives and detects the audio frequency (f_1-f_2) and this is called the position signal. The receiver is also tuned to the third frequency, f_3, and the reference signal is detected. The phase angle between the position signal and the reference signal is measured. These signals were each produced by the same two continuous-wave transmitters, but traveled to the receiver over two different paths.

The phase of the reference signal at the reference transmitter will be constant because the transmitter is fixed. The amplitude

modulation on the carrier f_3 is of constant phase if the distance from the mobile receiver to the reference transmitter is not too great (less than 50 nautical miles). However, if the receiver is moved, the position signal changes phase quite rapidly because the relative phase of the two continuous-wave radio frequencies changes rapidly.

The phase difference between the position signal and the reference signal depends on the location of the mobile receiver. If the receiver is moved so that the phase difference remains constant, the path followed will be a hyperbola with the two continuous-wave transmitters as the foci. As long as the difference in the distances to the transmitters remains constant there will be no change in phase. If the receiver moves in a path other than this hyperbola, a change of phase will occur.

There is an infinite set of constant phase hyperbolas generated by the two continuous-wave transmitters. If a receiver is placed in the network, it will lie along one particular hyperbola of the set. The midpoint of the line joining the two transmitters is chosen as a reference. The unique hyperbola passing through this point (a straight line) is assigned an arbitrary value, and all other hyperbolas in the network are assigned values using this central hyperbola as reference. The central hyperbola and each hyperbola differing from the central hyperbola by 360 degrees of phase form the boundaries of LORAC lanes. As the receiver crosses one lane it indicates a phase change of 360 degrees. The location of the receiver within each lane can be

determined by measuring the amount of phase change since crossing the boundary. A hyperbolic network with lane boundaries is shown in Figure 1(a).

Absolute positioning has not been accomplished since location along a hyperbola determines only one line of position. A second line of position is obtained by duplicating the entire network just described. The second set of transmitters is located so that the two sets of hyperbolas form a positioning grid in the area of intended use. Figure 1(b) shows the second set of hyperbolas and Figure 1(c) shows the grid formed by superposition of the two sets. One focus is common to both sets of hyperbolas. One set of hyperbolas and its associated equipment is called the GREEN half of the system and the other is called the RED half. The mobile receiver makes two phase measurements, one for each half of the system. Each of these measurements corresponds to a line of position in the appropriate set of hyperbolas. The position of the receiver is determined by the intersection of these lines of position.

B. THE LORAC-A SYSTEM

The basic LORAC system with two sets of hyperbolas would require six transmitters and four frequency channel assignments. LORAC-A offers a savings in equipment and frequency channels required. Three transmitters produce both sets of hyperbolas on a time-shared basis as shown in Figures 2 and 3.

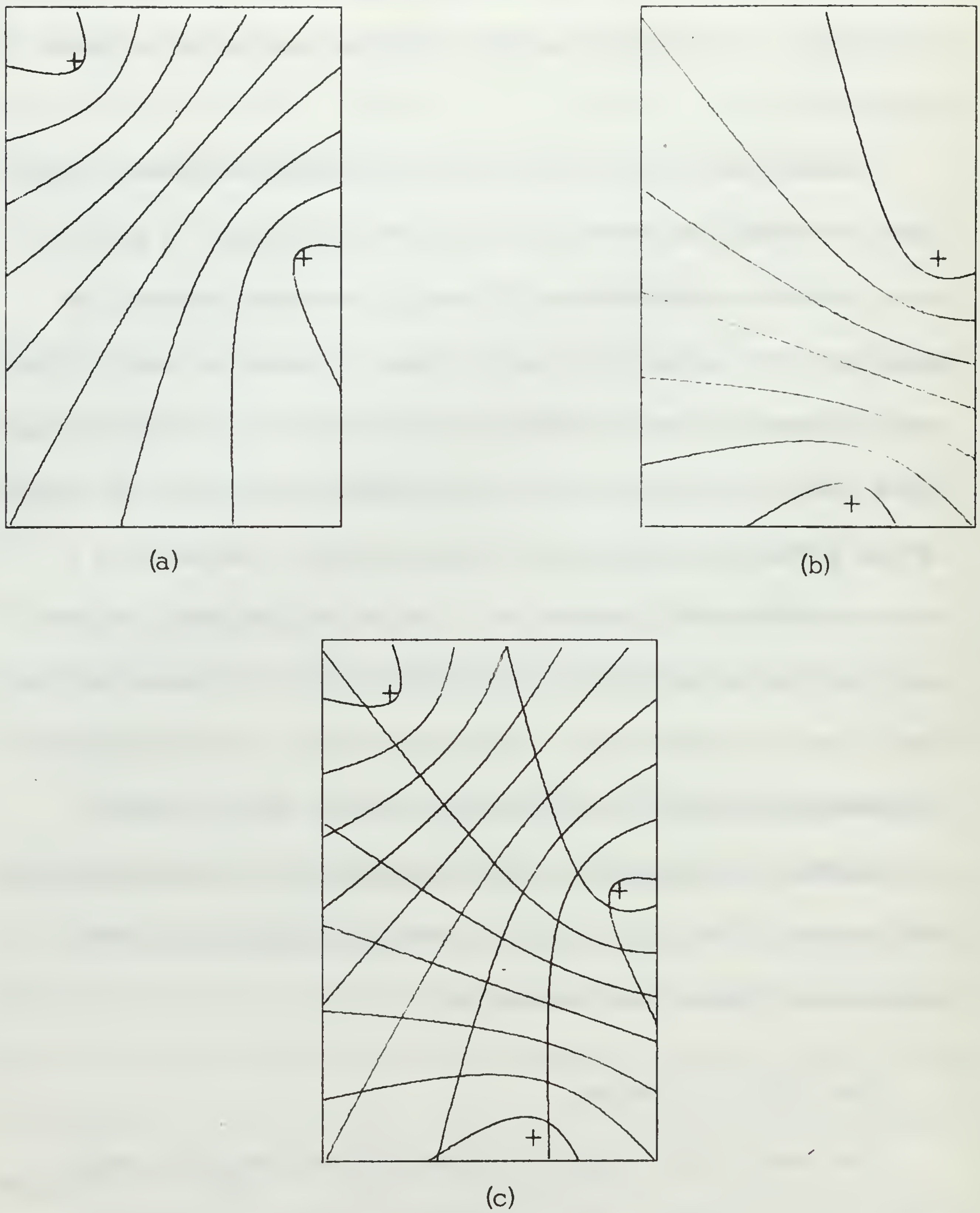


Figure 1. Hyperbolic Grid System

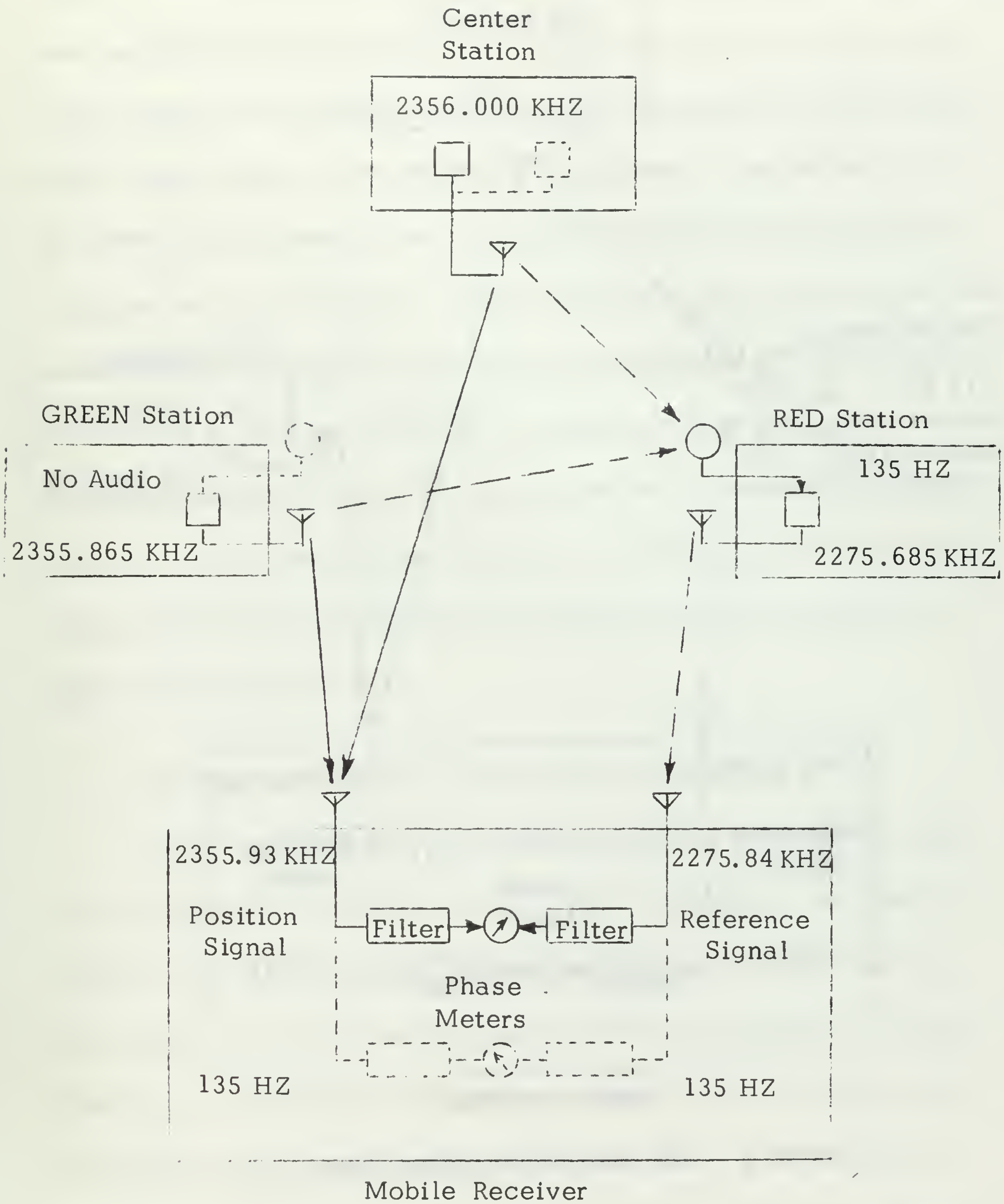


Figure 2. GREEN Half of Switching Cycle

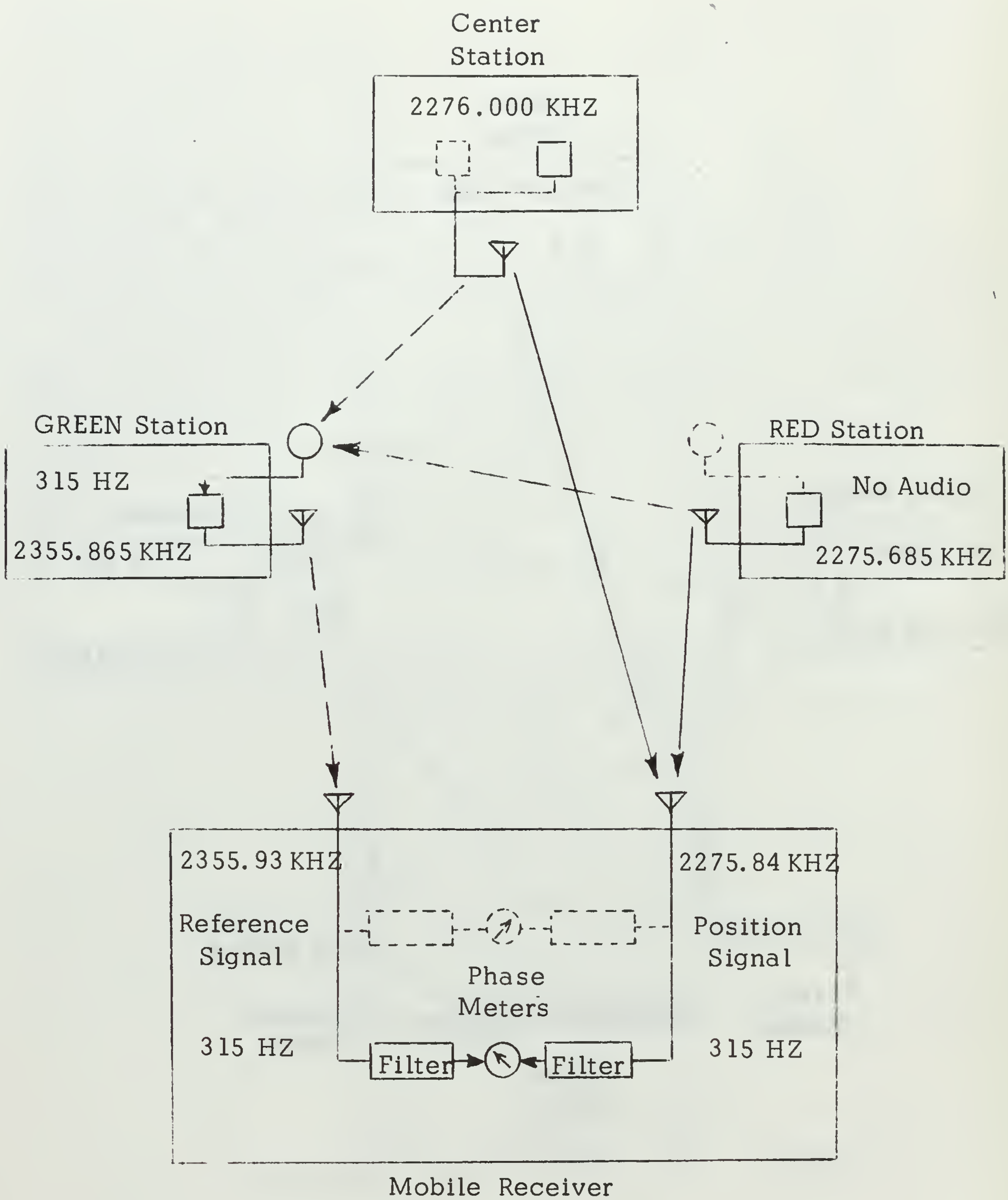


Figure 3. RED Half of Switching Cycle

During the GREEN half-cycle, the center station and the GREEN station transmit continuous-wave radio frequencies and the RED station acts as the reference transmitter. During the RED half-cycle, the center station and the RED station transmit continuous-wave and the GREEN station acts as the reference transmitter. The frequency of the center station determines the particular half-cycle in operation. Only one set of hyperbolas is being produced at any given instant and the center station switches periodically between two continuous-wave frequencies. The switching rate is rapid enough so that at the receiver it appears that both sets of hyperbolas are being produced simultaneously. The center station is a focus in both halves of the network, acting alternately with the GREEN and then the RED transmitter to generate the hyperbolas.

C. SYSTEM HISTORY AND EQUIPMENT DESCRIPTION

The present LORAC system was surplus and given to the Postgraduate School for operational use. The transmitters, receivers, recorder, and test equipment were manufactured by LORAC Service Corporation, a division of Seismograph Service Corporation, Tulsa, Oklahoma. Considerable time and effort was spent in restoring the equipment to operating condition. The equipment is about fifteen years old and uses tubes in most of the circuits. The transmitters are designed for a maximum output power of 300 watts. Four mobile receivers, one chart recorder, and numerous spare parts are available in the present system.

In 1968 LT Richard E. Shrum, USCG, undertook the system as a thesis project. Transmitters were installed in Santa Cruz, Moss Landing, and Monterey to provide LORAC coverage of Monterey Bay. His thesis, "Installation and Evaluation of LORAC Precise Navigation System," was used as a reference and to provide some of the groundwork for further investigations and testing.

II. SYSTEM PERFORMANCE

Performance of the system can be measured by observing two general parameters, stability and accuracy. Stability is measured by fixing as many of the variables involved as is considered practical and recording the variations due to the rest. Accuracy is measured by comparing theoretical receiver readings with those actually observed.

Stability measurements were made by establishing a monitor station in a fixed location and observing the variations in the receiver dial readings. Instrumental error was previously determined to be plus or minus one-half of a dial division (1/100th of a lane). This includes transmitter and receiver stability. Geometrical error is introduced by assuming that the earth is flat and the transmitting and receiving antennas are at the same elevation. This error for the vicinity of Monterey Bay was determined to be less than one meter and remains constant for a fixed receiver. Changes in the velocity of propagation will produce most of the error in a monitor station and the relative magnitude of these changes can be observed if dial readings are recorded over a period of time.

A. PHASE STABILITY MEASUREMENTS

The block diagram in Figure 4 shows the interconnection of components for data collection. The receiving antenna was a fifteen-foot whip mounted in a relatively clear area. No antenna coupler was used

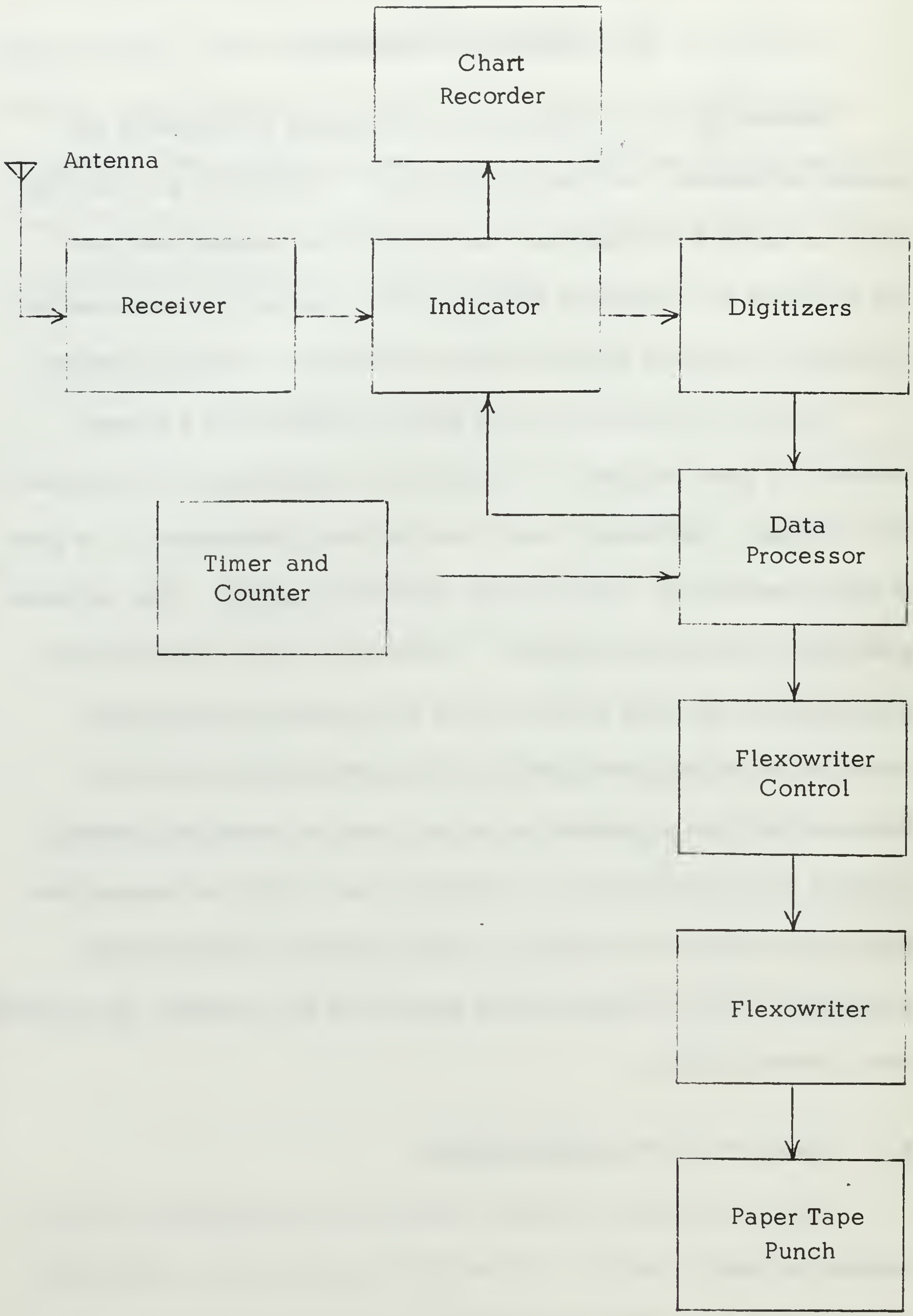


Figure 4. Monitor Station

with the receiver because signal strength was not increased with the coupler in the circuit. A shielded coaxial cable connected the antenna to the receiver. The shaft positions of the indicator unit were relayed to the chart recorder by synchro transmitters. These transmitters are included in the indicator circuit to drive external equipment. The recorder was used as a visual aid in evaluation of the dial reading variations and as a backup device in the event of a failure of the primary method of data collection.

The primary method of data collection was a digitizer which converts an analog shaft position to a digital readout. Two digitizers were connected directly to the indicator dial shafts by flexible control cables and couplings. Each has a resolution of 3.6 degrees, or 100 increments for one revolution. The output to the data processor can vary from 000 to 999 corresponding to ten revolutions of the digitizer shaft. The data processor converts each digitizer reading to serial commands to a flexowriter, first the GREEN reading, then the RED. Each dial on the indicator has a lane counter which changes with each revolution of the pointer. This counter indicates the lane location of the receiver and the pointer indicates the fractional location within that lane. The digitizers are calibrated so that the first digit corresponds to the last number on the lane counter. The second and third digits correspond to the pointer reading in hundredths of a lane. The flexowriter generates a typed copy of the readings and at the same time punches the data on paper tape. The typed copy was used as a check on the digitizer accuracy and the paper tape was used for processing the data.

A timing and counting unit was built to control the frequency of the observations and tabulate the number of readings taken during the recording period. A frequency of one observation per minute was considered more than adequate to detect a change in the average velocity of propagation. Random variations from minute to minute were assumed to be generated by noise superimposed on the radio frequency signals. This noise was taken into consideration in the data processing program.

1. Data Processing

A computer program has been written to process the data tape punched by the flexowriter. The complete program is included as Appendix A. Processing was done on a CDC-160 digital computer which accepts punched paper tape as input data. The CDC-160 has available a small FORTRAN II compiler stored on magnetic tape. The desired FORTRAN II program is punched on paper tape with a flexowriter, adhering to the format in the CDC-160 FORTRAN manual. This tape is called a source tape and is read by the compiler to produce an object tape. The object tape contains all the subprograms necessary for execution of the program. The source tape is no longer needed unless changes are to be made in the program. Each time the program is to be run all that is necessary is to read the object tape and any data tape required by the statements in the program. Output from the computer is on paper tape and can be read by a flexowriter to produce a typewritten copy.

The program written to process the data from the digitizers handles the readings in one-hour segments. The following computations are made for each block of 60 readings:

Mean (average)

Maximum

Time of maximum

Minimum

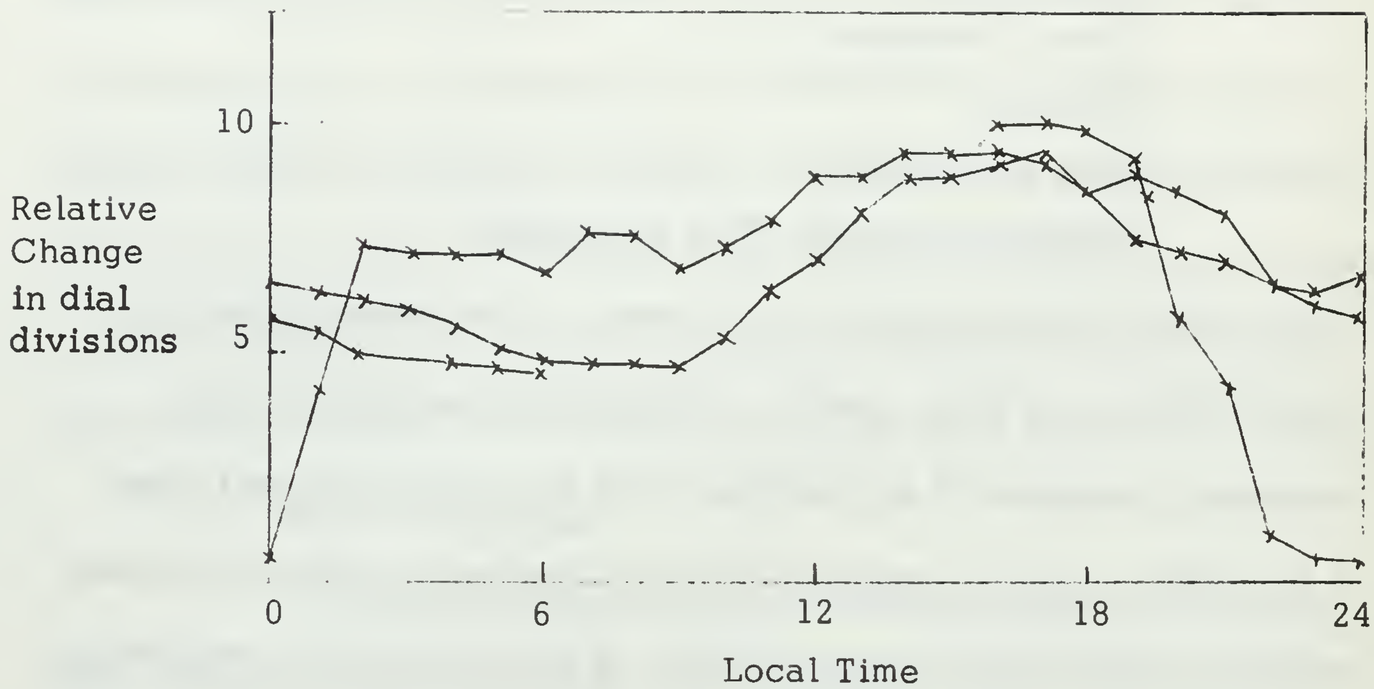
Time of minimum

Standard deviation (RMS component)

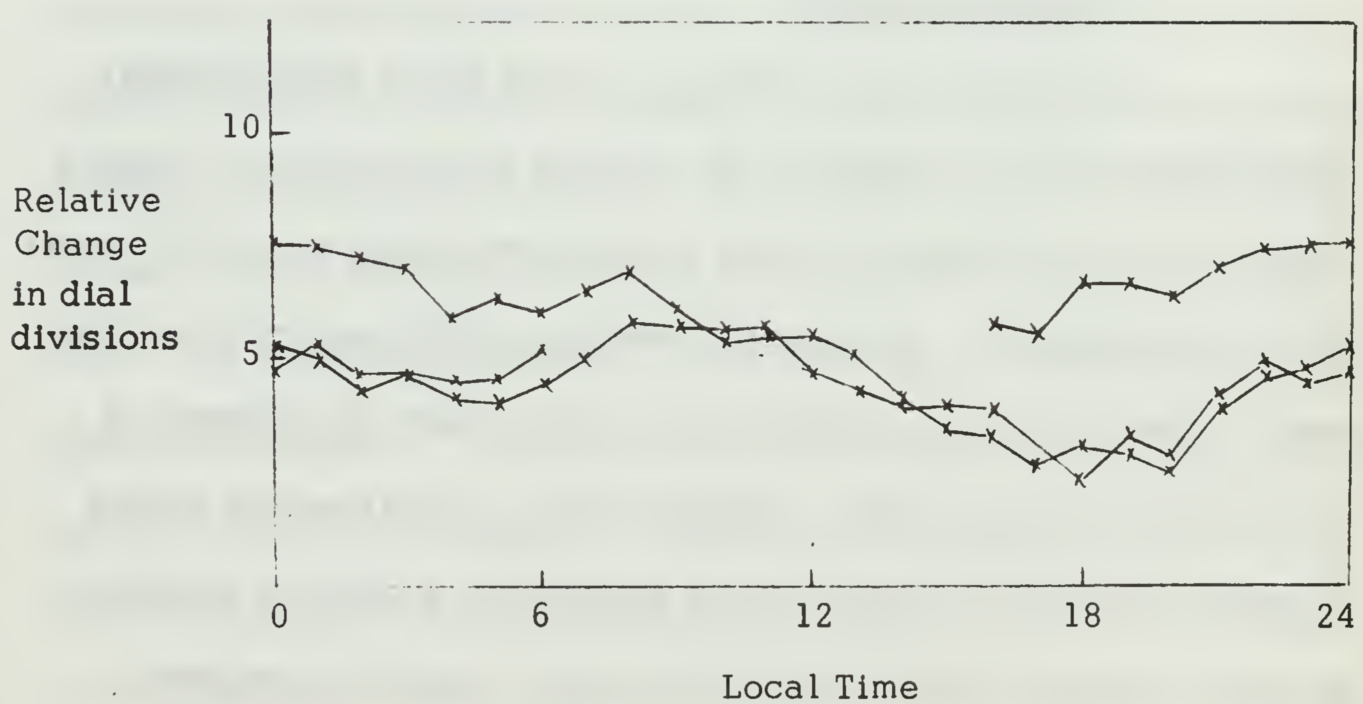
The standard deviation can be considered a noise error similar to a noise voltage on a D.C. level. It should be interpreted as the expected fluctuation of any reading about the average for that hour. If the RMS, or noise, error is relatively constant or varies with some periodic pattern over a regular interval of time, then some predictions can be made as to the expected noise level at any given time. Similar predictions may be possible for the average values.

2. Evaluation of Data

Variations in the average value of phase meter readings should reflect direct changes in the velocity of propagation. Figure 5 shows a plot of average values for a typical recording period (62 hours) in 24-hour intervals. All readings were taken with respect to an arbitrary reference since the charts for the system were not prepared at the time the data was taken. The plots show a considerable amount of drift during the first twelve hours followed by a periodic variation pattern. The initial drift can be attributed to a period of receiver stabilization and was evident in most of the extended periods of data collection. The periodic variations can be attributed to changes in velocity of propagation. The two plots do not show the same pattern



(a) GREEN Network



(b) RED Network

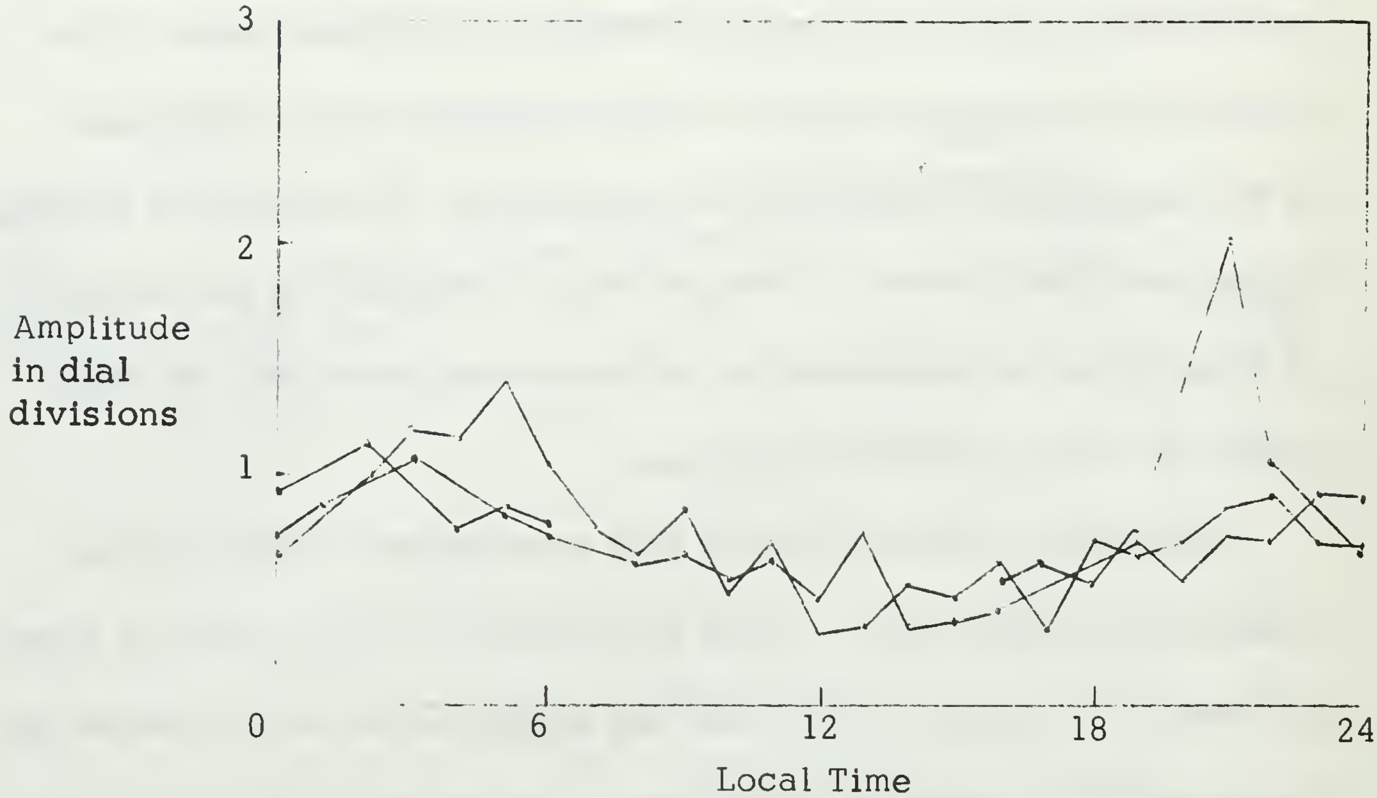
Figure 5. Average Phase Variations

for the RED and GREEN halves of the system. This is explained by the fact that the signals travel to the receiver over different paths. The direction and magnitude of phase change depends on the orientation of the receiver with respect to the transmitters. The amount of variation in phase for both halves of the system due to changes in the velocity of propagation was determined to be plus or minus two dial divisions within the area of intended operation.

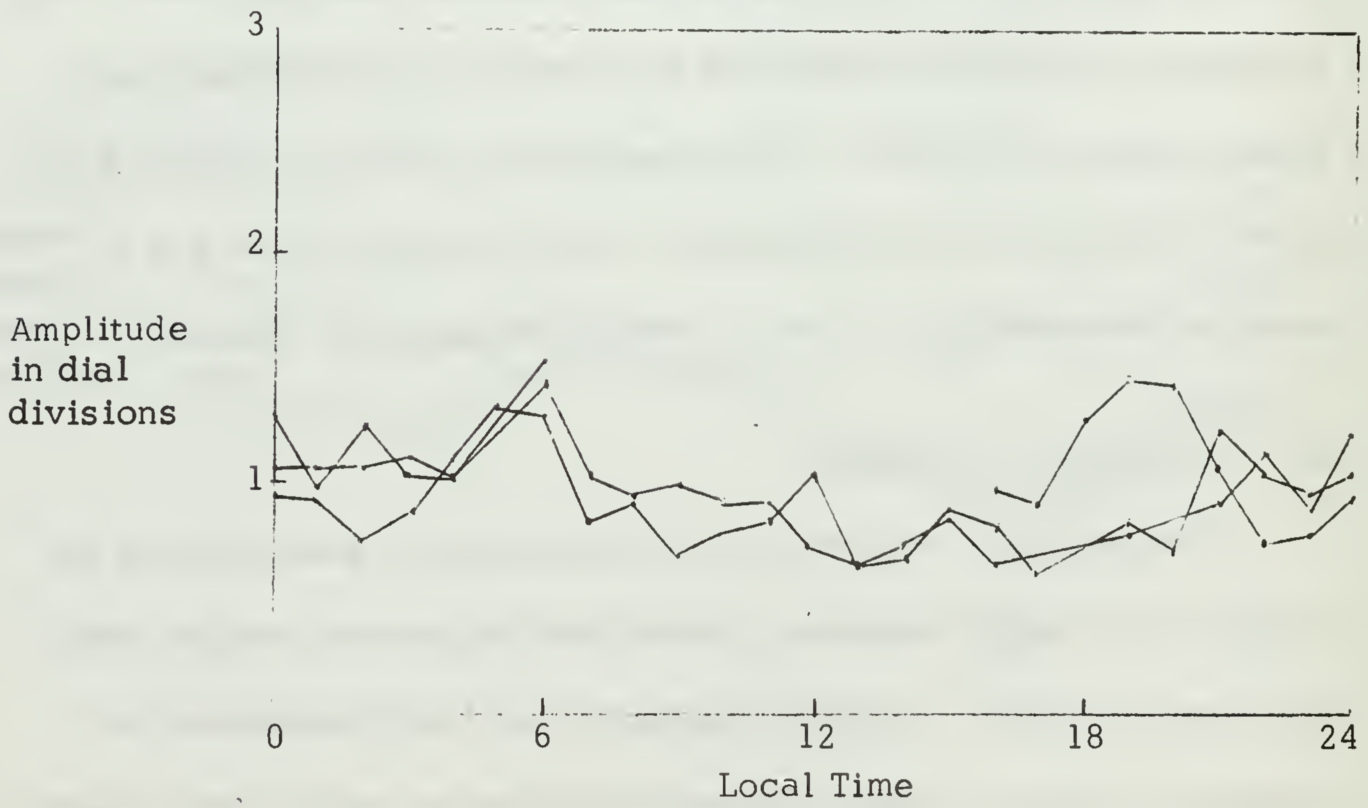
Variations in the calculated RMS error reflect changes in the noise level of the system. A plot of error for a 24-hour period is shown in Figure 6. The plots for the RED and GREEN halves of the system are very similar and appear to be periodic. The maximum noise level occurs between 2000 and 0600 and the minimum between 0800 and 1400. The error due to noise was determined to be about one dial division for a reading taken at any time. Closer predictions could be made, but the noise level at any one time changes widely from day to day and it would be more reliable to use an overall average as an estimate.

B. FREQUENCY STABILITY

The oscillator frequencies of the transmitters were initially set with a highly stable frequency counter and periodically verified with the same instrument. System accuracy is not highly dependent on frequency stability; in fact, the audio frequencies would have to drift outside the filters to produce any noticeable error. The center station was found to be the most stable of the three transmitters. After initial adjustment, the two frequencies of the center station did not drift



GREEN Half of Network



RED Half of Network

Figure 6. RMS Error Variations

more than plus or minus two cycles. The center station frequencies were considered constant during the remainder of the evaluation period.

After any adjustment was made to a transmitter, the audio frequencies were monitored to detect any drift. Frequency measurement was made by using the audio output from the monitor circuits in a receiver together with an adjustable audio oscillator output to produce a stable Lissajous pattern on an oscilloscope. A counter was used to measure the oscillator frequency. The audio signal from the system could not be measured directly due to the switching cycles. Most of the frequency drift occurred within six hours after energizing the transmitters. After the first few hours of operation, drift was negligible and settled to a rate of one or two cycles per week. Therefore, the best operation results if the oscillators are kept in operation. Adjustments in frequency during long periods of operation do not affect the drift rate and each oscillator should not have to be adjusted more than once a month.

C. EQUIPMENT RELIABILITY

Prior to energizing the entire system, each of the three transmitters were inspected for any visible defects in cable connections, antenna couplings, or similar items. Fuses were checked to insure that the correct size was being used. Prior to applying full power to the stations a variac was used to apply a low voltage to the power supplies and bring the units up slowly to the required line voltage. This allowed a period of time for moisture to evaporate and any

defects in the heater circuits to be observed. This precaution was used when energizing any of the transmitters after an inoperative period.

The entire system was placed in operation in August 1969 and as of November 1969, has been operating about 50% of the time. The inoperative time has been due to occasional failures and testing periods. Failures of the stations were due primarily to aging components and exposure to moisture. The transmitter at Santa Cruz had the most failures and this was attributed to its location at the end of the municipal wharf. Moisture was allowed to accumulate during the eight-month period that the system was not in operation. No single component in that transmitter was at fault. In contrast, the transmitter at Moss Landing is located in a furnace room which remains relatively warm and dry. Similarly, the transmitter in Monterey is well protected and a reasonable distance from the shoreline. Failures in the latter two stations have been infrequent, and mostly tubes and fuses have been at fault.

A spare parts box has been made up from the numerous spares available for the system. It contains tubes, fuses, and a few miscellaneous parts for the transmitters. This box is kept in the transmitter building at Monterey along with appropriate test equipment.

During the tuning of each transmitter about half the maximum power was coupled to the antenna. This was found to produce sufficient signal strength to operate the receivers in the Monterey Bay area. If operation is to be outside this area, additional power is available.

Operation is efficient and the standing wave ratios of the transmitting antennas are kept under 1.50. These ratios can be reduced if maximum power output is desired.

III. CHART OVERLAY PREPARATION

If the LORAC system is to be used for absolute position finding, then charts for the network must be prepared. If LORAC is used for repeatability of position, no chart is needed since all that is necessary is to move the receiver until the dials indicate a previously recorded reading.

A. CHOOSING A COORDINATE SYSTEM

The mathematical equations for the hyperbolic constant phase contours can be written in a number of coordinate systems. The simplest to use in a digital computer program is a two-dimensional rectangular coordinate system with perpendicular axes and identical scales in both directions. Most navigational charts, however, are constructed using a mercator projection and the result is a set of geographical coordinates. A hyperbolic grid cannot be conveniently constructed in geographical coordinates since the equation for a hyperbola in this system can only be approximated. A solution to the problem is to calculate points along a hyperbola in a rectangular coordinate system and then convert each point to geographical coordinates. LORAC grids are commonly generated in Universal Transverse Mercator (UTM) coordinates, a rectangular system with units of meters. Army Map Service charts, in UTM coordinates, are available for the Monterey Bay area and the coordinates of the transmitting sites can be easily estimated.

B. POINT GENERATION PROGRAM

A computer program has been written to generate points in the LORAC network for plotting, and has been used on the SDS-9300 digital computer. It follows the general description for generation of hyperbolic grid charts found in the Computer's Manual published by the LORAC Service Corporation. The program outputs data points on magnetic tape for plotting on a CALCOMP-563 plotter and is flexible enough to allow updating if the transmitting antennas are moved or the frequencies changed.

1. Input Data

The following information is read by the program into the computer from data cards:

GREENX, GREENY	Coordinates of the GREEN station (UTM)
CENTERX, CENTERY	Coordinates of the center station (UTM)
REDX, REDY	Coordinates of the RED station (UTM)
FREQ (1)	Frequency of the GREEN transmitter (hz)
FREQ (2)	Frequency of the RED transmitter (hz)
CENFR (1)	Frequency of the center station when operating with the GREEN station (hz)
CENFR (2)	Frequency of the center station when operating with the RED station (hz)
FREQM (1)	GREEN modulation (audio) frequency (hz)
FREQM (2)	RED modulation (audio) frequency (hz)
VELPROP	Velocity of propagation
L1	First row of conversion tables to be read
L2	Last row of conversion tables to be read
CI, CVII, CVIII, CIX, CX	One row of conversion tables

The dimensions and constants of the LORAC network are then calculated and arbitrary lane numbers are assigned to the center lane in each half of the network. The following chart parameters are introduced:

XMIN	The western boundary of the chart in geographical coordinates
XMAX	The eastern boundary of the chart
YMIN	The southern boundary of the chart
YMAX	The northern boundary of the chart
XSCALE	Scale of the chart in the X direction
YSCALE	Scale of the chart in the Y direction
DELU	Determines point density
UMAX	Determines size of the network generated
M	The interval of plotted lanes

The chart parameters are read from a single data card and a set of points for a complete chart is generated by each data card included in the program deck. Using magnetic tape as the output medium, there is essentially no limit to the number of sets of points that can be generated with one program run. The lane numbers of the points generated are listed by the line printer along with the graph number and the limits of the graph. The coordinates of the transmitter sites are also written on the magnetic tape for use in a point-plot. The entire program does not have to be rerun to duplicate a chart since the plotter is not an on-line output device and the data for the charts is stored on magnetic tape.

2. Subroutines

SUBROUTINE CONVERT is used in the main program to convert each hyperbolic set of points from UTM to geographical coordinates.

The subprogram is written using 36-00N and 123-00W as the origin for any point to be converted. A row of the conversion tables must be read into the program for every minute of latitude in the desired chart and linear interpolation is used for values between each minute. UTM coordinates are calculated to the nearest tenth of a meter and the conversion process carries out calculations to the nearest hundredth of a second of latitude (about one foot), losing little or no resolution in the conversion process.

The main program retains only those points that lie within the boundaries of the desired chart, and stores all lanes with more than one point. Since the latitude and longitude scales are not the same on a mercator projection, the horizontal units are reduced by the appropriate scaling factor found in mercator construction tables.

SUBROUTINE TAPEOUT prepares and writes the points on magnetic tape. The SDS-9300 is a 24-bit word digital computer which uses 2's complement arithmetic and the small computer that controls the plotter, the CDC-160, is a 12-bit word computer which uses 1's complement arithmetic. Some changes in format are necessary so that the output from the SDS-9300 can be read by the CDC-160. The subroutine scales the chart according to the values of XSCALE and YSCALE, limits the output points if they are too large for the CDC-160, and stacks the coordinates for more efficient use of magnetic tape. Each data point is stacked so that the first twelve bits of the SDS-9300 word contain the X coordinate and the last twelve contain the Y coordinate. The result

is a higher density of output points and an easier format for the CDC-160 to read. This subroutine can be used with any set of points and called with the following arguments:

X	The horizontal coordinate of each point
Y	The vertical coordinate of each point
IPC	The number of points
XSCALE	Scale in the X direction
YSCALE	Scale in the Y direction
MWIDE	Width of the horizontal field before scaling
MHIGH	Height of the vertical field before scaling

After scaling, the values of X and Y will be limited to plus or minus 2,047.

C. PLOTTING PROGRAM

The SDS-9300 computer does not have a plotter as an output device, so the points to be plotted were stored on magnetic tape. A CALCOMP-563 plotter was available and offered a plotting surface 30 inches wide and up to 100 feet in length. The plotter is controlled by commands from a CDC-160 computer and a general program was written for plotting lines, points, borders, and axes. The program will be discussed in some detail since no previous program was available and it may prove useful as a reference for future use of this system.

The CALCOMP-563 plotter will accept any one of ten instructions from the CDC-160:

Move carriage 0.005" in +X direction

Move carriage 0.005" in -X direction

Rotate drum 0.005" in +Y direction

Rotate drum 0.005" in -Y direction

Four combinations of the X and Y commands above to produce diagonal motion

Move pen down to paper

Move pen away from paper

Any program written must consist of combinations of these building blocks repeated the required number of times to move the intended distance and the intended direction.

The PLOT program will accept data points from any of the following sources:

Output from the CDC-160 FORTRAN II package

Paper tape output from the SDS-9300

Magnetic tape output from the SDS-9300

Manual entry from the CDC-160 console

The CDC-160 FORTRAN II package was described briefly in Chapter II. Using an OUTPUT statement in a program produces a punched paper tape in binary which can be read into a plotting program. Binary output is also produced by the SDS-9300 paper tape and magnetic tape outputs if an unformatted WRITE statement is used in a FORTRAN IV program. These last two formats are identical except for the END FILE characters which are used to separate sets of points. Data points may be entered in memory at the CDC-160 console, but this is a time-consuming process if more than a few points are needed.

The PLOT program selects the proper input device (paper tape reader or magnetic tape unit) then reads and stores all the points in memory for one line or point plot. Figure 7 illustrates the major control instructions in the program and the use of various subroutines. The pen is moved to the initial point and lowered to the paper. If the point-plot mode was selected, the pen draws a cross through the point and moves away from the paper; if the line-plot mode was chosen, the pen remains on the paper. The direction to the next point is determined by a slope calculation, and this slope determines which of sixteen different subroutines moves the pen. Each subroutine covers about twenty degrees of arc about the pen and is made up from the basic building blocks to move in a direction to bisect the arc. The slope is calculated after each movement of 0.005" and the appropriate subroutine is again chosen. This technique results in a relatively smooth curve if the line-plot is used with a data density of four or five points per inch. Much smoother curves are obtained as the density increases to the limit of 200 points per inch.

A general plotting program should utilize the entire 30-inch width of the paper and the largest integer that can be stored in the CDC-160 is 2,047 (positive or negative). A plotter step size of 0.005" makes available 200 addressable points per inch and if both positive and negative integers are utilized, the maximum graph width and height is 20.47 inches. To expand the graph size to the limits of the paper width, the addressable point density was reduced to 100 points per inch.

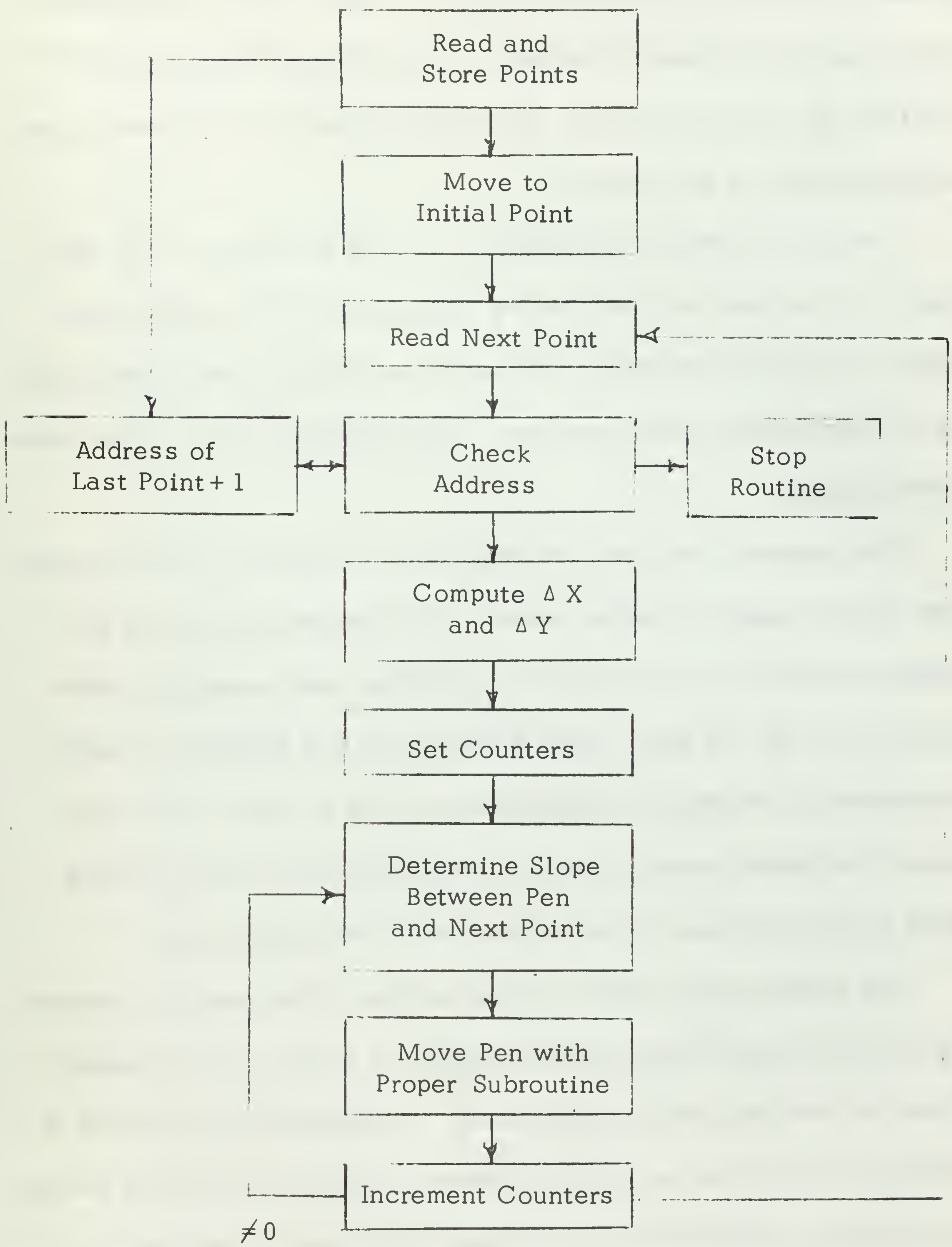


Figure 7. Plot Program Flow Diagram

This is done in the program by giving each pen movement command twice or doubling the distance between adjacent points. The higher density plotting mode is retained, however, and can be used if the graph is less than 20.47 inches square. The point density is determined by the starting address of the program.

Two graph sizes are available as a result of the change in point density. One graph is 20.47 inches square and has 200 addressable points per inch and the other is 30 inches wide, 40.94 inches high and has 100 addressable points per inch. The origin is located in the center of both graphs.

Two plotting modes were written into the program, one for plotting lines and the other for plotting points. Either mode can be used with either graph size. The subprogram for plotting lines reads and stores all the points for one line, draws a continuous line through the points, then returns to the origin and reads the next set of points. The subprogram for plotting points reads and stores one set of points, draws a plus sign at each point, then returns to the origin and stops.

The overall program has some restrictions. The maximum number of points that can be stored at any one time is 1,275, but any number of lines or sets of points can be plotted. The initial point on a line or the first of a set of points can be anywhere on the graph, but the change in successive coordinates cannot exceed 3.41" due to the slope calculating routines. This does not present a problem when drawing lines since the data density should be a few points per inch for a smooth curve.

It must be kept in mind, however, when using the point plot. An example of a prepared chart overlay is shown in Figure 8, illustrating the results of both the line plot and point plot modes.

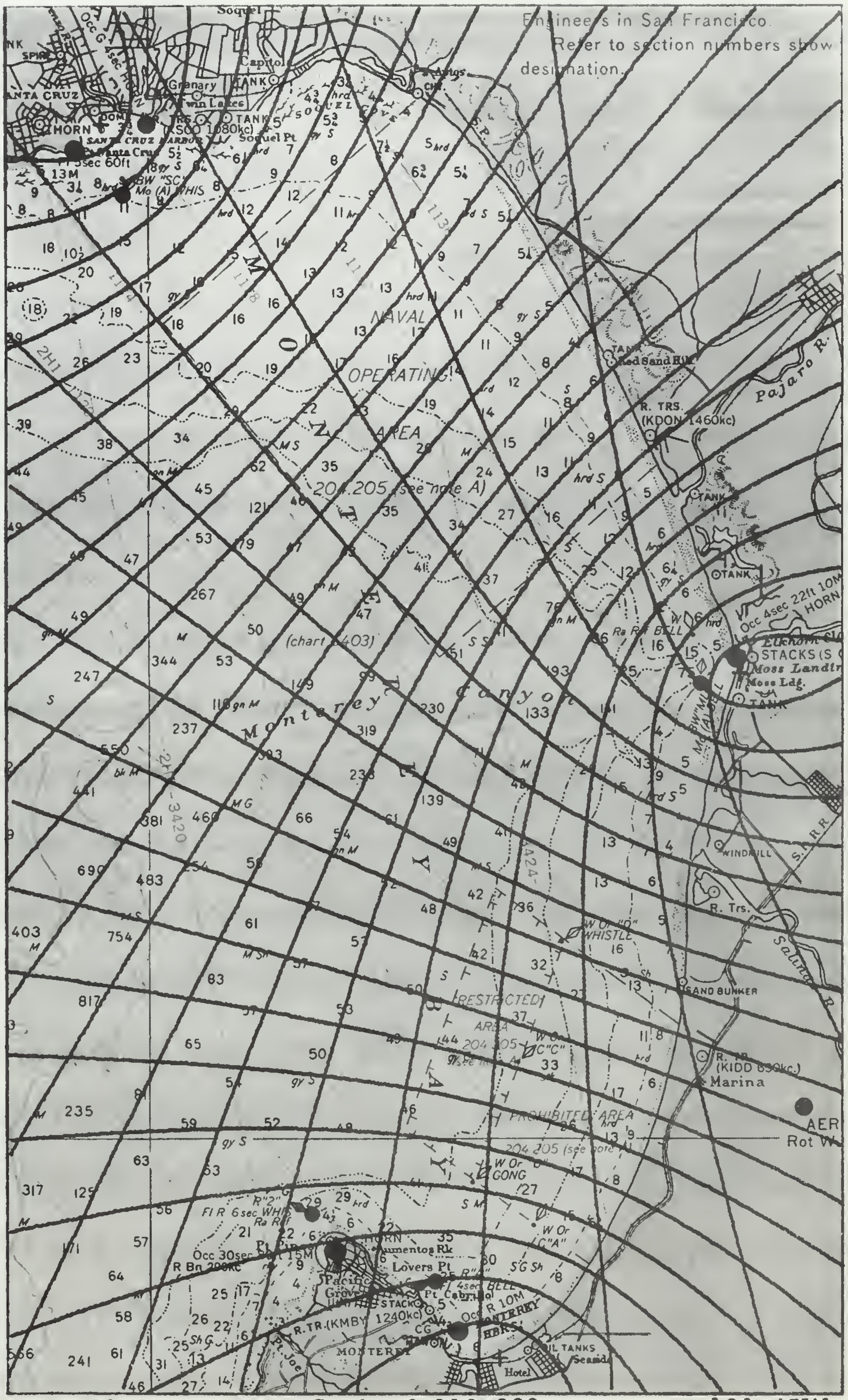


Figure 8. Sample Chart Overlay

IV. UPDATING THE SYSTEM

The present LORAC-A system was the first type in a series of hyperbolic phase comparison navigation systems manufactured by LORAC Service Corporation. Newer systems incorporate additional features such as lane identification and remote control to eliminate lane ambiguity and to make operation easier. The possibility of adding these two features to the existing system was investigated.

A. MODIFICATION AND TESTING

There are four receiver-indicator units for use with the system and each receiver was connected to its indicator by an eight-foot shielded cable. The two units were not easily separated and some difficulty was encountered in transporting the receivers. The cables were removed from three of the receivers and connecting jacks were mounted on the rear of the receivers and indicators. Short cables with connectors were made up to join the two jacks and these allow separation of the receiver and indicator when transporting or repairing. This modification also allows interchangeability of units which before was not easily accomplished.

A LORAC chart recorder for the system was repaired and an additional chart recorder was modified for use with the system.

Installation of a LORAC receiver on the Naval Postgraduate School research boat has been desirable since the navigation system was placed

in operation and some projects conducted in Monterey Bay require precise fixes, repeatability, and station keeping. A receiver was used on this boat in the past and some difficulty was experienced in positioning the indicator so that the dials were clearly visible to the helmsman. Disassembly of the indicator unit was considered undesirable due to the number of connections between components.

A remote indicator unit has been constructed to duplicate the dial and counter readings of the indicator. This unit has four synchro repeaters, two for the dials and two for the lane counters, which are driven by two synchro transmitters in the indicator. A multiple-conductor cable is connected to the output terminal board of the indicator.

A small chart recorder was adapted for use with the on-board receiver and a record of readings can be maintained. The recorder is connected by a six-foot cable to a jack mounted on the back of the indicator.

B. REMOTE CONTROL

It is desirable to place the three transmitters in a standby condition when the system is not being used. Standby condition may be defined as consisting of all heaters and blowers operating in the power supply, modulator, and RF amplifier, and the reference receiver and oscillator in full operation. These conditions insure frequency stability and minimize unnecessary radiation and warm-up time when full operation is desired. Available methods of remote control require

additional frequency assignments or leasing of landlines. The method proposed uses the frequencies already in use and has proven successful in laboratory tests.

Each mobile receiver contains two signal loss alarm circuits to indicate failure of either audio signal of the network. When a transmitter fails or signal strength falls below a certain level, an alarm lamp is energized on the indicator front panel. The signal loss alarm circuit uses the AGC level in the audio portion of the receiver to bias the grid of a relay control tube. A small relay in the plate circuit of this tube is held open under normal signal conditions. If the signal fails, the AGC voltage changes, the tube is cutoff, and the relay closes providing a return to ground for the indicator lamps.

The reference receivers in the transmitters at Santa Cruz and Monterey are essentially one half of a mobile receiver. The AGC circuits are the same but no signal loss alarm is used. The circuit boards are identical to those in the mobile receiver, however, with relay socket, tube socket, and wiring to a terminal strip. By simply inserting the proper tube and relay, the circuit operates the same as in the mobile receiver. This small relay can now be used to control the high voltage switches in the modulator and power supply.

Remote relays can be put in parallel with the high voltage switches and controlled by the relay in the reference receiver. This was done with the transmitter in Santa Cruz. The power supply in the reference receiver provides 250 volts d.c. which is used through dropping

resistors to energize the remote relays. The small relay in the reference receiver is single-pole, double-throw and has contacts rated at 250 ma. The relays used in the modulator and power supply each require five milliamps to energize and were wired in series to increase the voltage drop. Connections between units were made by using the spare wires in the wiring harness.

Limited success was attained with this circuit as a remote control device. The presence of an audio signal produced by the transmitters in Monterey and Moss Landing will hold the relays closed and keep the Santa Cruz transmitter in operation. When the signal is lost, however, the receiver noise level is high enough to also trigger the relays. The receiver used in the laboratory tests had a much lower noise level. Since all the circuit boards are interchangeable, it may solve the problem to exchange the AGC FILTER circuit boards in the two receivers.

This method of remote control has proven in theory that the presence of one signal is sufficient to control another. If the Monterey transmitter was placed in the standby condition, the loss of audio would be detected by the receiver at Santa Cruz and that transmitter would be placed in standby. The receiver would remain on and would be able to energize the rest of the units if the audio signal was again detected. If a similar circuit was placed in the transmitter at Monterey, then both transmitters could be controlled from the center station at Moss Landing. The system could also be controlled from one of the end stations but a receiver would have to be installed at Moss Landing.

C. LANE IDENTIFICATION

The LORAC-A system of position finding contains some lane ambiguities. Unless continuous reception and tracking of the signals is maintained, there is a possibility of losing track of the lane in which the mobile receiver is located. To reset the receiver to the proper lane number, its position must be known to within one lane width. On the baselines this is most critical since the lane widths are at a minimum of about 65 meters. Normal navigation methods such as radar, RDF, or LORAN do not offer this degree of fineness and some other method must be used.

Some methods of lane identification were investigated using the system itself. If another set of hyperbolic grids could be established with a lane width about ten times that of the basic system, it would be possible to use first a coarse lane reading then a fine lane reading for position finding.

One such method is based on a time difference principle similar to LORAN A. The end stations are transmitting continuously either CW or amplitude modulated. The center station switches periodically between two frequencies and the presence of the center station frequency produces both the reference signal and the position signal. The position signal is produced at the receiver as soon as the signal from the center station is received. The reference signal reaches the receiver at some later time because it took a longer path via the reference transmitter. If the time difference between the reception

of these two signals could be measured, it would produce two sets of hyperbolas using the same baselines as in the basic system.

There are inherent difficulties in trying to measure this time difference, however. The multivibrator that controls the switching rate in the center transmitter has a slow rise time compared to the time differences involved. In order to distinguish between lanes, a resolution of less than 65 meters is required. This distance is equivalent to about 0.2 microseconds resolution. A second drawback in the method is obvious; to measure time differences on the order of microseconds requires a bandwidth in megahertz, and the differences are only available at audio frequencies through audio filters.

Another method could be investigated using phase comparison techniques. The frequency difference between the red and green halves of the network is arbitrary. Presently, the difference is about 80 khz. If the two halves were separated by some audio frequency other than the ones already in the system, two more hyperbolic grids would be established. The basic frequencies would have to be adjacent assignments to avoid outside interference. This method is similar to LORAC-C which incorporates an additional transmitter to produce the audio signals for a coarse lane network.

V. RESULTS AND RECOMMENDATIONS

The LORAC system of hyperbolic phase comparison has shown to be a feasible and desirable navigation network for use on Monterey Bay. The transmitters and receivers have been reasonably reliable and the majority of failures were attributed to aging components combined with an eight-month inoperative period. If the system is kept in operation, the frequency of failure decreases and the stability of the system improves.

The most significant variational error in the system was caused by changes in the velocity of propagation of the transmitted signals. Direct observation showed a periodic variation due to these changes of plus or minus two dial divisions on the receiver. This variation produces a maximum error in the area of intended operation of plus or minus 20 feet. Since no reference position is required for repeatability of position, a receiver can be returned to a previously held position to within about 20 feet.

If an absolute position is to be determined, the coordinates of the transmitting antennas become important since they are used in the chart-producing program. Until the location of the antenna sites can be more precisely determined, the accuracy of an absolute position found with this LORAC system will be about 100 feet.

Considerable time and effort was spent on chart overlay preparation so that the system can be used for absolute position finding. The

accuracy of the overlays depends mainly on the accuracy of the data read into the program and the stability of the overall system. Sets of overlays have been made for the two most used charts of Monterey Bay, Coast and Geodetic Survey charts 5402 and 5403. On some overlays the lanes were plotted in colors (red and green) corresponding to the color designations of the two halves of the network. The plotting paper used is opaque and performs satisfactorily as an overlay, but clear mylar sheets for the plotter could be obtained if desired. The lanes could be plotted directly on the existing navigation charts, but a new chart would have to be plotted if a change in frequency or antenna location was made.

A general plotting program for the CALCOMP-563 was a secondary result of this project and can be used for any desired line or point plot within the integer limits of the CDC-160 computer.

It is recommended that the LORAC system as presently installed be kept in operation and used in conjunction with the ocean sciences research program at the Postgraduate School. Continued investigations of lane identification and remote control methods may prove valuable, but direct application may present some difficulties since the system is not designed with these features and is about fifteen years old. Definite consideration should be given to the possibility of replacing the present system with a more reliable and up-to-date LORAC system.

The prepared chart overlays should be compared to actual receiver readings and areas of disagreement investigated. Deviations are to be

expected where the signals pass over land or near large metallic structures. The areas in the vicinity of the transmitting antennas are also of interest.

The number of potential users of a navigational system on Monterey Bay is unlimited. Various research projects are being conducted by a number of organizations and a permanent, reliable navigation system, such as LORAC, would benefit many.

APPENDIX A

DATA PROCESSING PROGRAM

```
100     FORMAT (2I3)
101     FORMAT (2(3F8.2,I4,F8.2,I4,4X))
102     FORMAT (17X,5HGREEN, 40X,3HRED)
103     FORMAT (2(44H;;;AVE;;;;RMS;;;;;MAX;;TIME;;;MIN;;TIME;;;;))
        DIMENSION IX(60), IY(60)
        PUNCH 102
        PUNCH 103
60      XSUM=0.0
        YSUM=0.0
        DO 10 I=1,60
        READ 100, IX(I), IY(I)
        XSUM=XSUM+IX(I)
        YSUM=YSUM+IY(I)
10      CONTINUE
        XAVE=XSUM/60.0
        YAVE=YSUM/60.0
        XMAX=0.0
        XMIN=1000.
400     DO 20 N=1,60
        IF(XMAX-IX(N))300,301,301
300     XMAX=IX(N)
        N1=N
301     IF (XMIN-IX(N))20,20,401
401     XMIN=IX(N)
        N2=N
20      CONTINUE
        YMAX=0.0
        YMIN=1000.
600     DO 30 N=1,60
        IF(YMAX-IY(N))500,501,501
500     YMAX=IY(N)
        N3=N
501     IF(YMIN-IY(N))30,30,601
601     YMIN=IY(N)
        N4=N
30      CONTINUE
        XSQSM=0.0
        DO 40 K=1,60
        XSQ=(XAVE-IX(K))''2
        XSQSM=XSQSM+XSQ
```

```
40      CONTINUE
        XRMS=SQRTF(XSQSM/60.0)
        YSQSM=0.0
        DO 50 K=1,60
        YSQ=(YAVE-IY(K))''2
        YSQSM=YSQSM+YSQ
50      CONTINUE
        YRMS=SQRTF(YSQSM/60.0)
        PUNCH 101, XAVE, XRMS, XMAX, N1,XMIN, N2, YAVE,YRMS,YMAX,
       xN3,YMIN,N4
        PAUSE 7777
        GO TO 60
        END
        END
```

APPENDIX B

PLOTTING PROGRAM

Memory Location	Instruction Word	Machine Language
0000	7022	jpi 22
0001	7023	jpi 23
0002	7024	jpi 24
0003	7025	jpi 25
0004	7026	jpi 26
0005	7027	jpi 27
0006	7030	jpi 30
0007	7031	jpi 31
0010	7500	exc
0011	1161	1161
0012	7700	hlt
0013	0000	
0014	7037	jpi 37
0015	7036	jpi 36
0016	7035	jpi 35
0017	0000	
0020	0000	
0021	0000	
0022	2130	
0023	2133	
0024	2136	
0025	2141	
0026	2144	
0027	2147	
0030	2152	
0031	2155	
0032	0412	ldn 12
0033	4161	sti 61
0034	7067	jpi 67
0035	2351	
0036	1625	
0037	2000	
0040	0000	
0041	0000	
0042	2534	
0043	2500	
0044	2504	
0045	2530	
0046	2450	
0047	2466	
0050	2315	
0051	2350	
0052	0264	
0053	0370	
0054	2400	
0055	0231	
0056	2200	
0057	2400	
0060	0532	
0061	0577	
0062	1325	
0063	1363	
0064	0263	
0065	0310	
0066	2453	
0067	0100	
0070	7774	
0071	0000	
0072	4104	
0073	0013	
0074	7703	
0075	2600	
0076	0076	
0077	7715	
0100	2200	ldc
0101	3000	3000
0102	4213	stf 13
0103	7500	exc
0104	4102	4102
0105	7600	ina
0106	6401	zjb 01
0107	7600	ina

0110	0111	ls6	
0111	4077	std	77
0112	7600	ina	
0113	5077	rad	77
0114	4100	stm	
0115	3000		3000
0116	5701	aob	01
0117	4207	stf	07
0120	7600	ina	
0121	0111	ls6	
0122	4077	std	77
0123	7600	ina	
0124	5077	rad	77
0125	4100	stm	
0126	3012		0000
0127	5701	aob	01
0130	4313	stb	13
0131	0702	sbn	02
0132	4100	stm	
0133	0226		0226
0134	7600	ina	
0135	6526	nzb	26
0136	7101	jfi	01
0137	0150		0150
0140	1001		
0141	6012		
0142	6211		
0143	6311		
0144	2100		
0145	1001		
0146	6007		
0147	6206		
0150	7500	exc	
0151	4401		4401
0152	7440	otn	40
0153	2100	ldm	
0154	3000		3000
0155	6013	zjf	13
0156	6306	njf	06
0157	7401	otn	01
0160	0300	nop	
0161	0701	sbn	01
0162	6503	nzb	03
0163	6005	zjf	05
0164	0300	nop	
0165	7402	otn	02
0166	0601	adn	01
0167	6503	nzb	03
0170	2100	ldm	
0171	3001		3001
0172	6013	zjf	13
0173	6306	njf	06
0174	0300	nop	
0175	7404	otn	04
0176	0701	sbn	01
0177	6503	nzb	03
0200	6005	zjf	05
0201	0300	nop	
0202	7410	otn	10
0203	0601	adn	01
0204	6503	nzb	03
0205	7101	jfi	01
0206	0210		0210
0207	0701		
0210	2200	ldc	
0211	3000		3000
0212	4221	stf	21
0213	2200	ldc	
0214	3002		3002
0215	4220	stf	20
0216	2200	ldc	
0217	3001		3001
0220	4227	stf	27
0221	2200	ldc	
0222	3003		3003
0223	4226	stf	26
0224	2207	ldf	07
0225	3600	sbc	
0226	3236		0000
0227	6103	nzf	03
0230	7101	jfi	01
0231	0532		0000
0232	2500	lcm	
0233	3236		0000
0234	3100	adm	
0235	3240		0000
0236	4100	stm	
0237	1000		1000

```
0240    0300    nop
0241    0300    nop
0242    5707    aob    07
0243    5710    aob    10
0244    5707    aob    07
0245    5710    aob    10
0246    2500    lcm
0247    3237           0000

0250    3100    adm
0251    3241           0000
0252    4100    stm
0253    1001           1001
0254    0300    nop
0255    0300    nop
0256    5707    aob    07
0257    5710    aob    10

0260    5707    aob    07
0261    5710    aob    10
0262    7101    jfi    01
0263    0310           0310
0264    2200    ldc
0265    7401           7401
0266    4100    stm
0267    0160           0160

0270    4100    stm
0271    0551           0551
0272    0601    adn    01
0274    0164           0164
0275    4100    stm
0276    0544           0544
0277    0602    adn    02

0300    4100    stm
0301    0174           0174
0302    4100    stm
0303    0571           0571
0304    0604    adn    04
0305    7101    jfi    01
0306    0346           0346
0307    0000

0310    2100    ldm
0311    1000           1000
0312    6003    zjf    03
0313    6207    pjf    07
0314    6313    njf    13
0315    2100    ldm
0316    1001           1001
0317    6015    zjf    15

0320    6317    njf    17
0321    6215    pjf    15
0322    2100    ldm
0323    1001           1001
0324    6012    zjf    12
0325    6211    pjf    11
0326    6311    njf    11
0327    2100    ldm

0330    1001           1001
0331    6007    zjf    07
0332    6206    pjf    06
0333    6306    njf    06
0334    7101    jfi    01
0335    0224           0224
0336    7104    jfi    04
0337    7104    jfi    04

0340    7104    jfi    04
0341    7104    jfi    04
0342    0400
0343    1200
0344    0700
0345    1500
0346    4100    stm
0347    0201           0201

0350    4100    stm
0351    0564           0564
0352    2200    ldc
0353    5100           5100
0354    4100    stm
0355    0240           0240
0356    4100    stm
0357    0254           0254

0360    2200    ldc
0361    1000           1000
0362    4100    stm
0363    0241           0241
0364    0606    adn    01
0365    4100    stm
0366    0255           0255
0367    7101    jfi    01
```

0370	2510		0000
0371	0000		
0372	0000		
0373	0000		
0374	0000		
0375	0000		
0376	0000		
0377	0000		
0400	7500	exc	
0401	4401		4401
0402	7420	otn	20
0403	2100	ldm	
0404	1001		1001
0405	3100	adm	
0406	1001		1001
0407	3100	adm	
0410	1001		1001
0411	3500	sbm	
0412	1000		1000
0413	6331	njf	31
0414	6052	zjf	52
0415	3500	sbm	
0416	1000		1000
0417	6347	njf	47
0420	6040	zjf	40
0421	3500	sbm	
0422	1000		1000
0423	6335	njf	35
0424	6034	zjf	34
0425	2100	ldm	
0426	1000		1000
0427	3100	adm	
0430	1000		1000
0431	3100	adm	
0432	1000		1000
0433	3500	sbm	
0434	1001		1001
0435	6315	njf	15
0436	6052	zjf	52
0437	3500	sbm	
0440	1001		1001
0441	6347	njf	47
0442	6016	zjf	16
0443	6215	pjf	15
0444	0101	pta	
0445	7101	jfi	01
0446	0600		0600
0447	0101	pta	
0450	7101	jfi	01
0451	0403		0403
0452	0101	pta	
0453	7101	jfi	01
0454	0613		0613
0455	0101	pta	
0456	7101	jfi	01
0457	0403		0403
0460	0101	pta	
0461	7101	jfi	01
0462	0644		0644
0463	0101	pta	
0464	7101	jfi	01
0465	0403		0403
0466	0101	pta	
0467	7101	jfi	01
0470	0600		0600
0471	0101	pta	
0472	7101	jfi	01
0473	0644		0644
0474	0101	pta	
0475	7101	jfi	01
0476	0600		0600
0477	0101	pta	
0500	7101	jfi	01
0501	0644		0644
0502	0101	pta	
0503	7101	jfi	01
0504	0600		0600
0505	0101	pta	
0506	7101	jfi	01
0507	0403		0403

0510	0101	pta	
0511	7101	jfi	01
0512	0613		0613
0513	0101	pta	
0514	7101	jfi	01
0515	0644		0644
0516	0101	pta	
0517	7101	jfi	01
0520	0613		0613
0521	0101	pta	
0522	7101	jfi	01
0523	0644		0644
0524	0101	pta	
0525	7101	jfi	01
0526	0613		0613
0527	0101	pta	
0530	7101	jfi	01
0531	0403		0403
0532	7500	exc	
0533	4401		4401
0534	7440	otn	40
0535	2100	ldm	
0536	0233		0233
0537	4202	stf	02
0540	2100	ldm	
0541	3236		0000
0542	6013	zjf	13
0543	6306	njf	06
0544	0300	nop	
0545	7402	otn	02
0546	0701	sbn	01
0547	6503	nzb	03

0550	6005	zjf	05
0551	0300	nop	
0552	7401	otn	01
0553	0601	adn	01
0554	6503	nzb	03
0555	2100	ldm	
0556	0247		0247
0557	4202	stf	02
0560	2100	ldm	
0561	3237		0000
0562	6013	zjf	13
0563	6306	njf	06
0564	0300	nop	
0565	7410	otn	10
0566	0701	sbn	01
0567	6503	nzb	03
0570	6005	zjf	05
0571	0300	nop	
0572	7404	otn	04
0573	0601	adn	01
0574	6503	nzb	03
0575	0300	nop	
0576	7101	jfi	01
0577	2523		0000

0600	0603	adn	03
0601	4211	stf	11
0602	7401	otn	01
0603	2100	ldm	
0604	1000		1000
0605	0701	sbn	01
0606	4100	stm	
0607	1000		1000
0610	6025	zjf	25
0611	7101	jfi	01
0612	0447		0447
0613	0603	adn	03
0614	4211	stf	11
0615	7404	otn	04
0616	2100	ldm	
0617	1001		1001
0620	0701	sbn	01
0621	4100	stm	
0622	1001		1001
0623	6003	zjf	03
0624	7101	jfi	01
0625	0455		0455
0626	2100	ldm	
0627	1000		1000
0630	6003	zjf	03
0631	7101	jfi	01
0632	0403		0403
0633	7101	jfi	01
0634	0224		0224
0635	2100	ldm	
0636	1001		1001
0637	6003	zjf	03
0640	7101	jfi	01
0641	0403		0403
0642	7101	jfi	01
0643	0224		0224
0644	0603	adn	03
0645	4216	stf	16
0646	7405	otn	05
0647	2100	ldm	
0650	1000		1000
0651	0701	sbn	01
0652	4100	stm	
0653	1000		1000
0654	2100	ldm	
0655	1001		1001
0656	0701	sbn	01
0657	4100	stm	
0660	1001		1001
0661	6433	zjb	33
0662	7101	jfi	01
0663	0463		0463
0664	0000		
0665	0000		
0666	0000		
0667	0000		
0670	0000		
0671	0000		
0672	0000		
0673	0000		
0674	0000		
0675	0000		
0676	0000		
0677	0000		
0700	7500	exc	
0701	4401		4401
0702	7420	otn	20
0703	2100	ldm	
0704	1001		1001
0705	3100	adm	
0706	1001		1001
0707	3100	adm	
0710	1001		1001
0711	3100	adm	
0712	1000		1000
0713	6331	njf	31
0714	6047	zjf	47
0715	3100	adm	
0716	1000		1000
0717	6344	njf	44

0720	6036	zjf	36
0721	3100	adm	
0722	1000		1000
0723	6333	njf	33
0724	6032	zjf	32
0725	2100	ldm	
0726	1000		1000
0727	3100	adm	
0730	1000		1000
0731	3100	adm	
0732	1000		1000
0733	3100	adm	
0734	1001		1001
0735	6214	pjf	14
0736	6054	zjf	54
0737	3100	adm	
0740	1001		1001
0741	6251	pjf	51
0742	6014	zjf	14
0743	6313	njf	13
0744	0101	pta	
0745	7101	jfi	01
0746	1100		1100
0747	7101	jfi	01
0750	0703		0703
0751	0101	pta	
0752	7101	jfi	01
0753	1113		1113
0754	7101	jfi	01
0755	0703		0703
0756	0101	pta	
0757	7101	jfi	01
0760	1144		1144
0761	7101	jfi	01
0762	0703		0703
0763	0101	pta	
0764	7101	jfi	01
0765	1100		1100
0766	0101	pta	
0767	7101	jfi	01
0770	1144		1144
0771	0101	pta	
0772	7101	jfi	01
0773	1100		1100
0774	7101	jfi	01
0775	1002		1002
0776	0000		
0777	0000		
1000	0000		
1001	0000		
1002	0101	pta	
1003	7101	jfi	01
1004	1144		1144
1005	0101	pta	
1006	7101	jfi	01
1007	1100		1100
1010	7101	jfi	01
1011	0703		0703
1012	0101	pta	
1013	7101	jfi	01
1014	1113		1113
1015	0101	pta	
1016	7101	jfi	01
1017	1144		1144
1020	0101	pta	
1021	7101	jfi	01
1022	1113		1113
1023	0101	pta	
1024	7101	jfi	01
1025	1144		1144
1026	0101	pta	
1027	7101	jfi	01
1030	1113		1113
1031	7101	jfi	01
1032	0703		0703
1033	0603	adn.	03
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2441  0701  abn  01
2442  4070  std  70
2443  7101  jfi  01
2444  2273       2273
2445  2100
2446  0226
2447  0602

2450  2200  ldc
2451  7440       7440
2452  6103  nzf  03
2453  2200  ldc
2454  7420       7420
2455  4100  stm
2456  0402       0402
2457  4100  stm

2460  0702       0702
2461  4100  stm
2462  1202       1202
2463  4100  stm
2464  1502       1502
2465  7101  jfi  01
2466  2514       0000
2467  0000

2470  0000
2471  0000
2472  0000
2473  0000
2474  0000
2475  0000
2476  0000
2477  0000
```

```
2500   0101   pta
2501   0610   adn   10
2502   4153   sti   53
2503   7052   jpi   52
2504   0101   pta
2505   0604   adn   04
2506   4151   sti   51
2507   7050   jpi   50

2510   0101   pta
2511   0604   adn   04
2512   4147   sti   47
2513   7066   jpi   66
2514   2060   ldd   60
2515   4155   sti   55
2516   2065   ldd   65
2517   4164   sti   64

2520   0101   pta
2521   0603   adn   03
2522   4161   sti   61
2523   7054   jpi   54
2524   0000
2525   0000
2526   0000
2527   0000

2530   0101   pta
2531   0610   adn   10
2532   4153   sti   53
2533   7052   jpi   52
2534   0101   pta
2535   0604   adn   04
2536   4151   sti   51
2537   7050   jpi   50

2540   0101   pta
2541   0604   adn   04
2542   4147   sti   47
2543   7046   jpi   46
2544   0101   pta
2545   0610   adn   10
2546   4155   sti   55
2547   2062   ldd   62
```

```
2550   4164   sti   64
2551   2065   ldd   65
2552   4163   sti   63
2553   7054   jpi   54
2554   2060   ldd   60
2555   4163   sti   63
2556   0101   pta
2557   0604   adn   04

2560   4161   sti   61
2561   7062   jpi   62
2562   7700   hlt
2563   7101   jfi   01
2564   2544         2544
2565   0000
2566   0000
2567   0000

2570   0000
2571   0000
2572   0000
2573   0000
2574   0000
2575   0000
2576   0000
2577   0000
```

```
LORAC GRID GENERATION PROGRAM
      DIMENSION FREQ(2), BASE(2),HBASE(2),COSA(2),SINA(2),
     *WIDTH(2),TOTAL(2),MIDLN(2),ZH(2),ZK(2),X(1500),
     *Y(1500),CENFR(2),FREQM(2),
     *CI(100),CVII(100),CVIII(100),CIX(100),CX(100)
      READ(5,101) GREENX,GREENY,CENTERX,CENTERY,REDX,REDY,
     *FREQ(1),FREQ(2),CENFR(1),CENFR(2),FREQM(1),FREQM(2),
     *VELPROP
      READ(5,103)L1,L2
      READ(5,105)CI(K),CVII(K),CVIII(K),CIX(K),CX(K),
     *K=L1,L2
      MIDLN(1)=1000
      MIDLN(2)=2000
C     COORDINATES OF THE MIDPOINTS
      ZH(1)=0.5*(CENTERX+GREENX)
      ZK(1)=0.5*(CENTERY+GREENY)
      ZH(2)=0.5*(CENTERX+REDX)
      ZK(2)=0.5*(CENTERY+REDY)
C     BASELINE LENGTHS
      GRNDX=GREENX-CENTERX
      GRNDY=GREENY-CENTERY
      REDDX=REDX-CENTERX
      REDDY=REDY-CENTERY
      BASE(1)=SQRT(GRNDX**2+GRNDY**2)
      BASE(2)=SQRT(REDDX**2+REDDY**2)
      HBASE(1)=BASE(1)/2.0
      HBASE(2)=BASE(2)/2.0
      COSA(1)=GRNDX/BASE(1)
      SINA(1)=GRNDY/BASE(1)
      COSA(2)=REDDX/BASE(2)
      SINA(2)=REDDY/BASE(2)
C     DETERMINE LANE WIDTHS
      WIDTH(1)=VELPROP/(FREQ(1)+CENFR(1))
      WIDTH(2)=VELPROP/(FREQ(2)+CENFR(2))
C     COMPUTE THE TOTAL NUMBER OF LANES
      TOTAL(1)=BASE(1)/WIDTH(1)
      TOTAL(2)=BASE(2)/WIDTH(2)
C     FIND THE LANE NUMBERS AT EACH STATION
      GCENLANE=MIDLN(1)-TOTAL(1)/2.0
      GENDLANE=MIDLN(1)+TOTAL(1)/2.0
      RCENLANE=MIDLN(2)-TOTAL(2)/2.0
      RENDLANE=MIDLN(2)+TOTAL(2)/2.0
C     INTRODUCE THE CHART PARAMETERS
      IPLOT=1
 1000 READ (5,102)XMIN,XMAX,YMIN,YMAX,XSCALE,YSCALE,DELU,
     *UMAX,M
      OUTPUT(6) IPLOT
      MWIDE=(XMAX-XMIN)/1.243
      MHIGH=YMAX-YMIN
      IWIDE=MWIDE/XSCALE
      IHIGH=MHIGH/YSCALE
      OUTPUT (6) IWIDE,IHIGH
C     OUTPUT STATION COORDINATES FOR PLOTTING
      X(1)=GREENX
      Y(1)=GREENY
      IPS=1
      CALL CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
      IPC=1
      X(1)=(X(1)-XMIN)/1.243
      Y(1)=Y(1)-YMIN
      CALL TAPEJUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
      X(1)=CENTERX
      Y(1)=CENTERY
      IPS=1
      CALL CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
      IPC=1
      X(1)=(X(1)-XMIN)/1.243
      Y(1)=Y(1)-YMIN
      CALL TAPEJUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
      X(1)=REDX
      Y(1)=REDY
```

```
      IPS=1
      CALL CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
      IPC=1
      X(1)=(X(1)-XMIN)/1.243
      Y(1)=Y(1)-YMIN
      CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
C   CALCULATE THE NUMBER OF POINTS PER LINE
      IF(UMAX.NE.0.0)GO TO 20
      UMAX=2.0
   20 ICALC=UMAX/DELU+1.0
      ICALM=ICALC-1
C   CALCULATE THE POINTS TO BE PLOTTED, LANE BY LANE
      DO 100, K=1,2
      NCALC=TOTAL(K)/(2*M)+1
      NCALM=NCALC-1
C   FIND LANE NUMBER OF THE FIRST LANE TO BE PLOTTED
      DO 200, L=1,NCALC
      LANE=MIDLN(K)-(NCALC-L)*M
      A=(MIDLN(K)-LANE)*WIDTH(K)
      B=SQRT(HBASE(K)**2-A**2)
      OUTPUT(6) LANE
C   CALCULATE POINTS IN THE SECOND QUADRANT
      IP=1
      DO 300 IMU=1,ICALC
      U=UMAX-(IMU-1)*DELU
      E1=A*COSH(U)*COSA(K)
      N1=A*COSH(U)*SINA(K)
      E2=B*SINH(U)*SINA(K)
      N2=B*SINH(U)*COSA(K)
      XX=ZH(K)-E1-E2
      YY=ZK(K)-N1+N2
      X(IP)=XX
      Y(IP)=YY
      IPS=IP
      IP=IP+1
  300 CONTINUE
C   CALCULATE THE POINTS IN THE THIRD QUADRANT
      DO 400 IMU=1,ICALM
      U=UMAX-(ICALM-IMU)*DELU
      E1=A*COSH(U)*COSA(K)
      N1=A*COSH(U)*SINA(K)
      E2=B*SINH(U)*SINA(K)
      N2=B*SINH(U)*COSA(K)
      XX=ZH(K)-E1+E2
      YY=ZK(K)-N1-N2
      X(IP)=XX
      Y(IP)=YY
      IPS=IP
      IP=IP+1
  400 CONTINUE
      CALL CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
      IPC=0
      DO 30 N=1,IPS
      IF(.NOT.((XMIN.LE.X(N).LE.XMAX).AND.
     *(YMIN.LE.Y(N).LE.YMAX))GO TO 30
      IPC=IPC+1
      X(IPC)=(X(N)-XMIN)/1.243
      Y(IPC)=Y(N)-YMIN
30    CONTINUE
      IF(IPC.LE.1)GO TO 200
      CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
  200 CONTINUE
      DO 500 L=1,NCALM
      LANE=MIDLN(K)+L*M
      A=(LANE-MIDLN(K))*WIDTH(K)
      B=SQRT(HBASE(K)**2-A*A)
      OUTPUT(6) LANE
      IP=1
C   CALCULATE POINTS IN THE FIRST QUADRANT
      DO 600 IMU=1,ICALC
      U=UMAX-(IMU-1)*DELU
      E1=A*COSH(U)*COSA(K)
```

```
      N1=A*COSH(U)*SINA(K)
      E2=B*SINH(U)*SINA(K)
      N2=B*SINH(U)*COSA(K)
      XX=ZH(K)+E1-E2
      YY=ZK(K)+N1+N2
      X(IP)=XX
      Y(IP)=YY
      IPS=IP
      IP=IP+1
  600 CONTINUE
C CALCULATE POINTS FOR THE FOURTH QUADRANT
      DO 700 IMU=1,ICALM
      U=UMAX-(ICALM-IMU)*DELU
      E1=A*COSH(U)*COSA(K)
      N1=A*COSH(U)*SINA(K)
      E2=B*SINH(U)*SINA(K)
      N2=B*SINH(U)*COSA(K)
      XX=ZH(K)+E1+E2
      YY=ZK(K)+N1-N2
      X(IP)=XX
      Y(IP)=YY
      IPS=IP
      IP=IP+1
  700 CONTINUE
      CALL CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
      IPC=0
      DO 40 N=1,IPS
      IF(.NOT.((XMIN.LE.X(N).LE.XMAX).AND.
     *(YMIN.LE.Y(N).LE.YMAX)))GO TO 40
      IPC=IPC+1
      X(IPC)=(X(N)-XMIN)/1.243
      Y(IPC)=Y(N)-YMIN
40    CONTINUE
      IF(IPC.LE.1)GO TO 500
      CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
  500 CONTINUE
  100 CONTINUE
      DO 75 N=1,20
      X(N)=(N-1)*MWIDE/20.
75    Y(N)=0.
      DO 76 N=21,40
      X(N)=MWIDE
76    Y(N)=(N-21)*MHIGH/20.
      DO 77 N=41,60
      X(N)=(60-N)*MWIDE/19.
77    Y(N)=MHIGH
      DO 78 N=61,80
      X(N)=0.
78    Y(N)=(80-N)*MHIGH/20.
      IPC=80
      CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
      IPLOT=IPLOT+1
      GO TO 1000
101   FORMAT(2F20.1)
102   FORMAT(6F10.2,2F6.3,I3)
103   FORMAT(2I3)
105   FORMAT(5F12.3)
      END

      SUBROUTINE TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
      DIMENSION IX(1500),IY(1500),IXY(1500),X(1500),Y(1500)
      DO 25 N=1,IPC
      IX(N)=(X(N)-MWIDE/2.0)/XSCALE
      IY(N)=(Y(N)-MHIGH/2.0)/YSCALE
      IF(-2047.LT.IX(N)) GO TO 1
      IX(N)=-2047
1     IF(2047.GT.IX(N))GO TO 2
      IX(N)=2047
2     IF(-2047.LT.IY(N))GO TO 3
      IY(N)=-2047
3     IF(2047.GT.IY(N))GO TO 4
```

```
      IY(N)=2047
4     IF(IX(N).GE.0)GO TO 5
      IX(N)=IX(N)+4095
5     IX(N)=IX(N)*4096
      IF(IY(N).GE.0)GO TO 6
      IY(N)=IY(N)+4095
6     IXY(N)=IX(N)+IY(N)
25    CONTINUE
      DO 10 I=1,10
      IF(((I-1)*128.LE.IPC).AND.(((I-1)*128+13).GT.IPC))
     *GO TO 15
10    CONTINUE
      GO TO 7
15    DO 20 K=(IPC+1),((I-1)*128+13)
20    IXY(K)=0
      IPC=(I-1)*128+13
7     WRITE (4) IXY(N), N=1,IPC
      END FILE 4
      RETURN
      END


      SUBROUTINE CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
      DIMENSION X(1500),Y(1500),CI(100),CVII(100),
     *CVIII(100),CIX(100),CX(100)
      DO 17 N=1,IPS
      E=X(N)-500000.
      Q=E*1.E-06
      QSQ=Q*Q
      QCUBE=QSQ*Q
      QFOURTH=QCUBE*Q
      IF(Y(N).GT.CI(L1))GO TO 14
      Y(N)=CI(L1)
      X(N)=0.
      GO TO 17
14    IF(Y(N).LT.CI(L2))GO TO 16
      Y(N)=CI(L2)
      X(N)=0.
      GO TO 17
16    DO 27 K=L1,L2
      IF(Y(N).LE.CI(K))GO TO 28
27    CONTINUE
28    L=K-1
      DELTA=(Y(N)-CI(L))/(CI(K)-CI(L))
      YP=(L-1)*60.+DELTA*60.
      DVII=CVII(L)+DELTA*(CVII(K)-CVII(L))
      Y(N)=(YP-DVII*QSQ+CVIII(L)*QFOURTH)*100.
      DIX=CIX(L)+DELTA*(CIX(K)-CIX(L))
      DX=CX(L)+DELTA*(CX(K)-CX(L))
      X(N)=(DIX*Q-DX*QCUBE)*100.
17    CONTINUE
      RETURN
      END
```

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13. ABSTRACT

A LORAC system of navigation has been established in the Monterey Bay area and is intended for use in the field of ocean sciences research. It operates on a phase comparison principle and provides highly accurate navigational fixes without complex timing circuitry. Short-term phase stability of the system was studied and methods of remote control and lane identification were investigated. Some equipment modifications were made to incorporate desirable features in the system, but further modernization may be necessary if long periods of continued use are expected. A general plotting program for the CALCOMP-563 plotter was written to produce chart overlays for existing navigational charts and is included as Appendix B. The overlays can be tailored to fit any scale chart in the area of intended operation and the inputs to the grid generation program can be varied if the system parameters are changed.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Navigation System, Precise						
2. LORAC						
3. Position Fixing						
4. Hyperbolic Navigation System						

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